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Contributors

Selman, Geoffrey George

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change frequency. A superheterodyne receiver was used, so that a common I.F. amplifier could be used on all frequencies. For the reasons already discussed a common transmit and receive system was used. It was decided to include time calibration marks and a strobe time-base, in case it was desired to measure velocity.

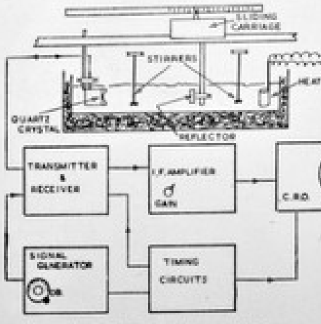


Figure 3. Schematic diagram of the apparatus.

A schematic diagram of the apparatus is shown in Figure 3. It is identical in principle with that of Pellam and Galt (1946). The main difference is that in this case the output from a signal generator is passed through a calibrated attenuator before injection into the amplifier to provide a standard for comparison. The amplitude of an echo is compared on an oscilloscope with that of a pulse from the signal generator injected into the quartz crystal itself. Variations in the gain of the amplifier affect both signals equally and consequently introduce no error in the measurement.

We now consider the design of the more important items in detail.

(a) *Mounting the Crystal*

If the assumptions made in the discussion of §2 are to be justified the crystal must be held quite flat in its mount, and must not be distorted by stirring of the liquid. A mounting which supports the crystal from behind is essential; an unsupported crystal was found to be distorted seriously if the liquid was stirred. The mounting adopted was kindly suggested to the author by Mr. T. Gold.

The main part of the mount is a cylindrical brass block 2 in. in diameter, bored out to take a ¾in. diameter dystrene plug, which in turn has a central brass plug of ⅜in. diameter. These parts are slightly tapered and forced into one another. The end of the cylinder is ground flat and polished and the crystal is held against it by a clamping ring and rubber washer. The area of crystal excited is determined by the brass plug which forms the live electrode. The use of rubber washers prevents measurement in liquids such as benzene which diffuse into rubber. A mounting is now under development in which the crystal is soldered into position.

The crystals used are X-cut, 1 in. in diameter and gold-plated on the face in contact with the liquid. The plating is continued round the edge to cover a ring on the reverse side extending inwards for 1/16 in. This ring serves to earth the plating on the front. The provision of the ⅛in. unexcited border to the crystal has been found to reduce a tendency to spurious modes of oscillation resulting in false echoes immediately following the transmitter pulse.

(b) *Mechanical Adjustments*

From §3 we see that it is necessary to have two angular adjustments to the position of the crystal mounting and two angular and two linear adjustments to the position of the reflector. The angular adjustments are made by spring-loaded screws at the ends of short levers, and geometrical slides provide the linear adjustments. All the adjusting mechanisms for the reflector are mounted on a sliding carriage running on two 1 in. steel bars, to which the adjusting mechanism for the crystal is clamped. The bars are supported above the trough containing the liquid by four pillars screwed on to a 6 in. channel iron baseplate. The whole assembly has the required exceptional rigidity and is mounted on rubber to prevent shocks from vibrating the reflector.

(c) *Irises and Reflectors*

We have already said that it may be desirable to restrict the effective diameter of the crystal by an iris. If multiple reflections of the pulses occur between the crystal and the iris the numerous echoes visible on the oscilloscope obscure the wanted signal. This difficulty may be avoided by making the iris in the form of a truncated cone, with a hole bored through the narrower end, so that sound striking the cone is reflected sideways and does not return to the crystal. A cone of 45° semi-angle should be avoided otherwise the radiation can return along its own path if reflected from the sides of the tank. The cones are made of brass and rigidly supported with the aperture a few millimetres from the surface of the crystal. The aperture is chosen to make z_0 the desired value (cf. §3).

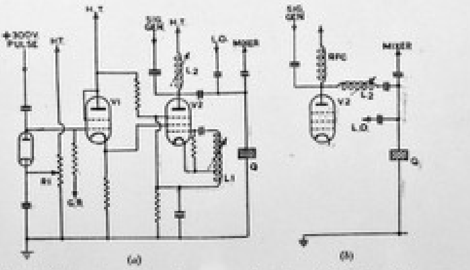
The reflectors are of two kinds. The large plane reflector, for use in the Fresnel region, is made of brass ⅛in. thick and 1 in. square. The surface is ground and polished. The accuracy required in the surface is λ/4 at 70 Mc/s., which is approximately 1/1,000 in.

Small reflectors to be used in the Fraunhofer region must project forward about one inch from the supporting rod, so that the latter gives an independent reflection which can be ignored. The tip of the reflector should be plane and slightly larger than the supporting shank. Brass reflectors of 1 mm. and 2 mm. diameter have been used successfully at 7·5 and 15 Mc/s.

(d) *Transmitter-Receiver Unit*

The circuit of the transmitter-receiver unit has certain unusual features. The aim of the design is to reduce the number of tuned circuits required, and the arrangement adopted uses three on each of five frequencies involving fifteen

preset adjustments to the tuning. A simplified circuit diagram is given in Figures 4(*a*) and 4(*b*). The frequency of oscillation is determined by the grid-cathode circuit of the oscillator valve, which is a 6AG7 pentode. The coil in the anode of the oscillator acts as tuned circuit both for the transmitter output and for the receiver input and a diode mixer is connected directly across this circuit. The local oscillator E.M.F. and an R.F. pulse from the signal generator are also fed into this tuned circuit. The oscillator valve is switched on by a positive pulse on its screen. To prevent oscillations from continuing after the end of the pulse the screen normally has a negative bias of about 20 volts generated in the cathode circuit.



(*a*) (*b*)

Figure 4. (*a*) Circuit of transmitter and quartz crystal at 7·5 and 22·5 Mc/s. (*b*) the same rearranged for the frequencies 37·5, 52·5 and 67·5 Mc/s.

At high frequencies the total inductance required in the anode circuit becomes very small; the inductance of the coil itself may then be so small in comparison with that of the leads that tuning is impossible. On the two lowest frequencies all the stray capacities appear in parallel, as is evident from the circuit of Figure 4(*a*); on the higher frequencies, however, the total stray capacity is divided into two parts appearing in series with one another across the coil by the rearrangement shown in Figure 4(*b*). In this way a coil may be used which is large enough compared with the lead inductance to be easily tuned.

Owing to the necessity for changing frequency it is not possible here to match both ends into the screened lead connecting the crystal to the oscillator. A switched matching circuit in the crystal housing itself, which is below the surface of the liquid, was considered impracticable. It was therefore essential that this lead be kept as short as possible. The transmitter and receiver circuits, with the local oscillator and first I.F. amplifier stages, were therefore designed as one small unit which could be mounted just above the troughs containing the liquid.

The power output from the quartz crystal is controllable by varying the size of modulation pulse fed to the screen of the 6AG7. The bias on the diode can be set to limit the pulse at the grid of V_1; thus the setting of the potentiometer R_1 controls the power output from the oscillator.

(e) *Other Electrical Circuits*

The other electrical circuits follow normal radar practice; it will therefore be sufficient to state the types of circuits used. The whole equipment runs at a recurrence frequency of 250 c/s. determined by a crystal calibrator taken from a Gee Mk II equipment (Dippy 1946). The pulse modulating the transmitter is generated by a multivibrator (Williams 1946) and is variable in length from 2 to 40 microseconds. The pulse modulating the signal generator is variable in width and is delayed a variable amount by a Phantastron circuit (Williams and Moody 1946). The main I.F. amplifier on 15 Mc/s. is taken from an H_2S Mk II radar set (Carter 1946) and is modified to include a cathode follower feeding the output to the oscilloscope and a neon stabilizer to control the voltage on the screens. The Sanatron time base (Williams and Moody 1946) has three ranges of 80, 400 and 2,000 microseconds duration. A very stable delay using the Sanatron was made to allow a variable delay of from about 300 to 2,000 microseconds in the start of the time-base. This feature allows the time-base to be used as a strobe if accurate measurements of velocity are made. The signal generator is a commercial model fitted with a piston attenuator; it covered all the frequencies used in the measurements.

(f) *Temperature-controlled Bath and Thermostat*

Several troughs have been employed depending on the liquid concerned. For water a double walled trough 5 ft. in length was made and water could be circulated in an outer jacket from a thermostat. For liquids having a higher absorption than water, heating in a small lagged trough with an electric heater controlled by a Variac proved satisfactory. The temperature could be controlled manually to a satisfactory degree of accuracy. In the trough run two high speed stirrers of ½in. diameter. The speed is controlled so that bubbles which might get in the beam and alter the amplitude of the echo are not sucked down into the liquid. Temperature is measured with ordinary mercury thermometers calibrated in tenths of a degree Centigrade. At temperature below 0° C. a pentane thermometer is used. To cool the liquid below room temperature solid carbon dioxide and liquid air are employed. The refrigerant is placed in a small can immersed in the liquid. Whether or not the temperature is sufficiently uniform for accurate readings to be taken can be seen immediately from the oscilloscope. If the echo is varying constantly in size the temperature is not uniform throughout the liquid.

§5. METHOD OF CARRYING OUT AN EXPERIMENT

(i) *Setting up the Apparatus*

The setting up falls naturally into two parts, concerned with the electrical circuits and mechanical adjustments respectively.

The width of the transmitted pulse was made just wide enough to give a flat top to the echo seen on the oscilloscope. The power output was adjusted so that when the reflector was at minimum range the signals could be accepted by the receiver without overloading. This could be detected by setting the pulse from the signal generator at various points on the time-base and noting